THE WILMOT SURVEY TYPE STRONG-MOTION EARTHQUAKE RECORDER

(The U.S.C.G.S. Seismoscope)

Part II

by

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1. Summary. The results of laboratory tests on the adjustment, accuracy, and performance of the seismoscope are given. The effects of stylus pressure, record plate curvature, method of adjustment, and other factors on the damping characteristics of the pendulum were experimentally investigated, and the results are embodied in recommendations for a standard procedure for the field installation and checking of the instrument. The accuracies of such basic instrument parameters as period and tilt sensitivity were established, and the overall level of duplicability of results attained by typical instruments was determined. A comparison of the behavior of similar instruments made by different manufacturers was made. The results of field tests involving the measurement of actual ground motions caused by blasts and earthquakes are given. The location of some 50 of the Wilmot seismoscopes in a network covering the Los Angeles area is given, together with available information as to local geology and soil conditions at the seismoscope sites.

2. Introduction. The need for a simplified instrument for the measurement of strong-motion earthquake ground motions has been discussed in a series of reports and papers (ref. 1-7). A special device has been developed for this purpose by a cooperative effort involving the United States Coast and Geodetic Survey, the California Institute of Technology, the University of California at Los Angeles, the Earthquake Engineering Research Institute, and the National Science Foundation. The basic theory of the instrument, as well as complete constructional details and the results of preliminary tests,

have been given in a special report, which may be considered as Part I of the present report (ref. 4). Subsequent to the initial tests, field tests involving the measurement of actual earthquake ground motions were made, and the results obtained were compared directly with the complete information calculated from strong-motion accelerograph recordings (ref. 7).

The present report constitutes Part II of ref. 4, and includes the results of numerous tests relating to the routine application of the instrument. This is a final report summarizing the work done at the California Institute of Technology on the development of this recorder.

3. Studies of Instrument Damping. Preliminary tests indicated that the most critical adjustment of the device was the pendulum damping. Not only is the damping the main adjustable parameter, which can be set at different values, but the value set is not independent of the amplitude of the pendulum motion. The stylus friction is not negligible compared with the eddy current damping provided by the permanent magnet system, and the resultant total damping was found to decrease with pendulum amplitude. It thus becomes important to study the various influences which can change the damping, and to establish a standard installation and check procedure that will insure reproducible results with a given instrument and comparable results with a large group of instruments.

4. Effect of Stylus Pressure on Damping. In Fig. 1 is shown a number of experimental damping determinations at various stylus pressures. It is evident that there is an influence of stylus pressure which is appreciably larger than the experimental scatter of the points. It was concluded that if the stylus pressure was set within the range 3/4 to 1-1/4 grams, the

variations would be insignificant compared with other uncertainties. The stylus pressure specification adopted by the Seismological Field Survey of the U. S. Coast and Geodetic Survey has accordingly been set at 1± 1/4 gram. (ref. 8).

5. Effect of Glass Record Plate Curvature on Damping. During preliminary tests it was noted that various "standard" watch glasses of the same nominal diameters varied over a wide range as far as curvature was concerned. It was found that the glasses obtained from chemical or biological supply houses were more variable in this respect than those obtained from jewelers' supply houses. Significant differences were found in the damping tests results using plates of markedly different curvatures. In Fig. 2 are shown results obtained with two types of watch glass with different curvatures. The "VTF" glass plate has a curvature which corresponds closely to the geometry of the pendulum system, while the low curvature plate is distinctly flatter, and hence causes an appreciable vertical stylus motion during large pendulum motions. The low curvature glass gives a measurably smaller damping, by an amount slightly greater than the experimental scatter. It was accordingly decided that the 2-1/2 in. "VTF" glass plate (manufactured in France) would be established as the operating standard (ref. 8). This type of plate is widely available at jewelers' supply houses, and apparently is held to sufficiently close tolerances for the present application.

6. Effect of Repeated Tests on Damping. In Figs. 3 and 4 are shown results of damping tests made on a particular instrument at different times. No adjustments of any kind were made on the instrument during the test interval. The object of the tests was to check the effects of time and normal

handling on such items as the smoke coating on the glass plate, friction at various points, and on the magnet system. It will be seen from Figs. 3 and 4 that no definite trends are established, and that the scatter of points for all of the tests at different times and different amounts of instrument checking and handling is approximately that of an undisturbed test. Although the time interval involved is too short to definitely settle some questions concerning the long-term behavior of the smoked coating on the glass plate, it appears that standard test procedures and ordinary handling would not be expected to introduce appreciable errors.

7. Duplicability of Results. A good idea of the overall accuracy to be expected from the instruments can be obtained by subjecting several instruments simultaneously to the same base motion. A comparison of the records obtained in such a test will give a direct indication of the accuracies to be expected in routine use of the device.

A series of such simultaneous tests were made on pairs of instruments in various combinations. The two instruments were mounted together on a rigid base plate which was constrained in such a way that only horizontal translational motions could be applied. This elimination of rotational effects insured that the base motion would be the same for both instruments. It was found that with a little practice the whole system could be given by hand an irregular two-dimensional horizontal motion that would produce a record similar to that caused by a typical strong-motion earthquake. In part I of the present report it was shown by acceleration-time measurements that such methods could produce motions very similar to those of strong-motion earthquakes (ref. 4).

In the first series of tests the two instruments of each test were adjusted to have as nearly the same damping characteristics as possible. Fig. 5 shows the damping tests for one such pair, and Fig. 6 shows a magnified photograph of the resulting record plates. Figs. 7 and 8 give similar data for another typical test. The results of a number of such tests are summarized in Table I, which indicates the quantitative agreement between the various instruments. The numbers given there represent average values determined by measuring a number of the corresponding peaks on the two simultaneous records.

Additional simultaneous shaking tests were made in which the damping of the two instruments was deliberately made different. Fig. 9 shows the damping curves for these tests, and Figs. 10 and 11 give the results of two typical simultaneous shaking tests. In each case an amplitude ratio was determined which was an average of several prominent peaks near a single amplitude of 0.3 inch, in the middle of the damping curve of Fig. 9. For the test of Fig. 10, the lower damped instrument gave an average reading 10% higher than the other instrument, while for the test of Fig. 11 the average reading of the lower damped instrument was about 8% higher. These values may be compared with the theoretical ratios calculated on the basis of a random input (ref. 4, 9). From Fig. 9 the damping values for the two cases are found to be about 11% and 9% of critical damping. The deflection ratios under random motions would thus be:

$$\sqrt{\frac{0.11}{0.09}} \approx 1.10$$

indicating a 10% increase, which compares closely with the above results. It thus appears that the correction factors for small damping deviations which have been suggested in the first part of this report (ref. 4) check well with experiments.

It will be seen from Fig. 9 that at the larger deflections the difference in damping between the two instruments increases, and thus the ratios between the deflections should increase. This is in fact the case, and it will be seen in Figs. 10 and 11 that at the largest deflections the ratios are greater than the average values at intermediate amplitudes given above.

It has been noted that the damping measurements are influenced to some extent by the shape of the recorded patterns. Patterns which tend to be circular will give a measurably different damping curve than flat patterns, in which the displacement in one direction is much larger than in other directions. In the standard procedure report of ref. 8 it is recommended that a circular spiral damping test be used, and that the setting of 10% of critical damping at a single amplitude of 0.35 inch be adopted as standard.

8. Tilt Sensitivity Tests. Numerous tilt tests were made on various Wilmot instruments to check the uniformity of the pendulum angle-record plate deflection relationship. No significant differences were found in tilt sensitivity between different instruments or different directions of pendulum motion. Since in field applications there may be some question as to the exact properties of the particular replaceable flexure pivot being used, it is recommended that a standard tilt sensitivity test be made at each installation or re-adjustment of the instrument (ref. 8).

9. Comparative Tests on the Sprengnether Instrument. The test work

reported above and in Part I (ref. 4) was all done on seismoscopes* manufactured by the Wilmot Engraving & Instrument Co., Pasadena. Similar instruments have been manufactured for the U. S. Coast and Geodetic Survey by the W. F. Sprengnether Instrument Co. of Saint Louis. These Sprengnether instruments were intended to be identical to those manufactured by Wilmot. The photograph of Fig. 12 shows the two Seismoscopes, the one on the left being the Wilmot. Except for minor differences in materials and the methods of manufacturing of certain of the parts, and in surface finishes, the two devices are believed to be identical.

To get a direct comparison of the two seismoscopes, one of the Sprengnether instruments was tested simultaneously with a Wilmot instrument, with a common base motion. The damping curves of the two instruments were adjusted to be as near alike as possible, with the results shown in Fig. 13. It is evident that the damping behavior of the Sprengnether seismoscope is effectively identical to that of the Wilmot instrument. Tilt sensitivity tests indicated that the Sprengnether instrument had a measurably different tilt sensitivity. The ratio of the tilt sensitivity of Sprengnether Seismoscope No. 1618 to that of Wilmot No. 142 was determined to be 1.16. Since only one Sprengnether seismoscope was available for test, the uniformity of tilt sensitivity of these instruments could not be investigated. Variations of tilt sensitivity would not be important in practice, however, since tilt tests are made on each seismoscope as a part of the standard installation and check procedure (ref. 8).

Figs. 14, 15, and 16 show the results of the simultaneous tests. As would be expected from the greater tilt sensitivity of the Sprengnether

* The name "seismoscope" has been agreed upon as a simple descriptive term for the instrument, although the device is in effect more than is implied by the past associations of the word. A more exact name would be "Single Period Response Spectrum Recorder", although this is obviously too cumbersome for everyday use.

seismoscope, this instrument gives somewhat larger records. By comparing the magnitudes of the corresponding peaks over the range of amplitudes covered by the damping tests, the average ratios of the uncorrected Sprengnether amplitudes to the Wilmot amplitudes are: Test No. I (Fig. 14) - 1.14; Test No. II (Fig. 15) - 1.18; Test No. III (Fig. 16) - 1.10. If these numbers are corrected by the factor of 1.16 which relates the tilt sensitivity of the two instruments, the ratios become 0.98, 1.02, and 0.97. The percentage deviation between the Sprengnether and the Wilmot for these three tests are thus seen to be 2%, 2%, and 3%. Comparing these figures with those given in Table I, it is evident that the agreement between this particular pair of Sprengnether and Wilmot seismoscopes is at least as good as the average agreement to be expected between typical Wilmot instruments. By comparing Figs. 14, 15, and 16 with Figs. 6, 7, 10, and 11 it will be noted that the similarity in general appearance of the records is as good between the Sprengnether and the Wilmot instruments as between the various Wilmot instruments tested.

Although only one of the Sprengnether seismoscopes was available for test at this particular time, it is understood that the experience of the U. S. Coast and Geodetic Survey with a group of 45 of the Sprengnether instruments indicates a satisfactory level of uniformity. On the basis of the above tests and the experience of the U. S. Coast and Geodetic Survey it is concluded that the Sprengnether and the Wilmot seismoscopes are dynamically equivalent for the intended application.

10. Design Changes in the Standard Seismoscope. Since Part I of the present report (ref. 4) was issued, several small design changes have been

introduced. These changes have had no effect on the dynamics of the device, but are aimed at simplifying the installation and adjustment of the instrument.

The original Wilmot seismoscope, shown in the drawings of ref. 4, was provided with two 1/4 inch diameter holes in the baseplate for mounting on the foundation. These holes have been increased to 3/8 inch diameter for greater ease in installation.

It was found by the U. S. Coast and Geodetic personnel installing the seismoscopes that a window in the top of the stainless steel cover would permit checking of the instrument condition, by means of a flashlight, without the need to remove the cover. This not only saves some inspection time, but eliminates the possibility that the scriber assembly might be disturbed while removing or installing the cover. On all new models, a 2-1/4 inch diameter hole has been cut in the top of the cover, midway between the handle and the front edge. This hole is then sealed with a 1/8 inch thick disk of lucite, plexiglass, or other transparent material.

On some of the seismoscopes that had been in service for many months, there was some evidence of corrosion of the piano-wire flexure pivot. In order to eliminate any possibility of troubles from this source, it is recommended that some type of corrosion-inhibiting treatment be given to the pivot assemblies. One such treatment, which has been tried with apparent success, is to give the whole pivot assembly a flash gold plating. The expense of this operation is negligible, and this should be an effective way of providing a suitable corrosion-resisting surface without otherwise disturbing the properties of the material or the assembly.

11. Field Tests of the Seismoscopes. The desirability of tests of the seismoscope under actual field conditions of installation and adjustment, with a

check of the ability of the instrument to measure correctly the horizontal ground motions while acted upon by strong vertical accelerations, was realized from the start. The first opportunity for a check of this kind occurred during a large quarry blast at Corona, California, on February 18, 1960. The only seismoscopes available at that time were early development models which differed in important respects from the final design. At that stage in the development, detailed studies of the factors influencing instrument accuracy had not yet been made. The quantitative results of these early tests are thus of no significance for an evaluation of the current standard seismoscope. The tests did indicate, however, that the presence of strong vertical accelerations did not disturb the operation of the instrument in any important way. This conclusion was of some importance in view of questions which had arisen concerning the effects of vertical accelerations in altering the pendulum period. It is well known that ground motions at right angles to the direction of motion of a pendulum type seismograph may induce instabilities at certain critical frequencies. Calculations have indicated that this effect should be negligible with the present instrument under the type of vertical excitation to be expected during strong-motion earthquakes (ref. 7).

The first measurement of an actual earthquake ground motion with the standard seismoscope occurred on 11 December 1958 at the Stanford Research Institute, Menlo Park, California. The Stanford Research Institute had purchased one of the Wilmot instruments and installed it on the concrete slab of a small building. The adjustment of the instrument was completed just in time to pick up the third aftershock of a local earthquake. The main shock of 11 December 1958 had a Gutenberg-Richter magnitude of 4.7, and an epicenter about 10 miles from the seismoscope. The measured after-shock was evaluated as having a maximum Modified-Mercalli intensity IV, as compared with a rating of VI for the main shock. The results of this test indicated that satisfactory measurements could be made with the seismoscope for even relatively small local earthquakes. Since no recording accelerographs were located in the vicinity, there was no opportunity to make a quantitative check of the seismoscope measurements.

Important opportunities to check the quantitative behavior of the seismoscopes under actual earthquake conditions occurred during the Hebgen Dam, Montana, Earthquake of 27 August 1959 (an aftershock of the major Montana earthquake of 18 August 1959), and the Hollister, California, Earthquake of 19 January 1960. During these earthquakes, standard seismoscopes were installed beside standard U. S. Coast and Geodetic Survey Strong-Motion Accelerographs so that a direct comparison of measurements could be made. Complete response spectrum calculations of the measured earthquake ground acceleration-time curves were made, so the values of these response spectrum curves at the standard seismoscope parameters of $T = 0.8$ second and $n = 10\%$ of critical damping could be determined. The results of the comparison of the seismoscope measurements with the complete response spectrum determinations are summarized in Table II. Complete details of these tests are given in ref. 7, from which the data of Table II have been taken.

It can be concluded from Table III that the standard U. S. C. G. S. Seismoscope, when installed and adjusted according to the recommended procedure (ref. 8), gives a satisfactory agreement with complete response spectrum analysis. It is believed that the order of accuracy indicated in Table II is entirely adequate for the intended application of the instrument.

12. <u>The California Seismoscope Network.</u> In view of the satisfactory performance of the seismoscope as indicated by the above tests, it was decided to establish a trial network of instruments to cover certain seismically interesting areas in California.

The funds provided by the National Science Foundation were sufficient to construct 57 of the standard instruments which were manufactured by the Wilmot Engraving and Instrument Co. through an arrangement with the California Institute of Technology. These instruments were mostly installed in the Southern California region. An additional 45 seismoscopes for installation in the San Francisco area were purchased from the Sprengnether Instrument Co. by the U. S. Coast and Geodetic Survey. Responsibility for the installation and maintenance of all seismoscopes was assumed by the Seismological Field Survey of the U. S. Coast and Geodetic Survey, since an important purpose of the instruments was to supplement the existing U. S. Coast and Geodetic Survey network of strong-motion accelerographs.

A special committee of the Earthquake Engineering Research Institute was formed to study the problem of locating the seismoscopes. Professor C. Martin Duke of the University of California at Los Angeles was the chairman of this committee, which included W. K. Cloud, P. Byerly, M. A. Ewing, and D. E. Hudson. David J. Leeds of the University of California at Los Angeles assisted with these studies, and made many of the arrangements for the installation of the seismoscopes. In deciding on the optimum instrument locations, such factors as local geology, seismicity, population density, soil conditions, and distribution with respect to existing accelerograph stations were considered. A number of the sites were chosen to correspond with those used by Professor Gutenberg in his studies of the effects of ground on earthquake motion (ref. 10). The seismic regionalization investigations of Professor Richter were also kept in mind during these studies (ref. 11).

Before installation, all seismoscopes were shop adjusted and tested by a standard procedure developed by Richard P. Maley, Geophysicist, Seismological Field Survey, U. S. Coast and Geodetic Survey, who also prepared a standardized procedure for the field installation and checking of the instruments (ref. 8).

Fig. 17 is a map indicating the locations of the California stations. Fig. 18 shows a more detailed picture of the stations in the Los Angeles region, in which seismoscope locations are shown in relation to the basic geology of the area. A list of the Wilmot Seismoscopes, with available information as to present location, local geology, and ground conditions is given in Table III.

In addition to the 57 Wilmot Seismoscopes purchased with National Science Foundation funds, 3 of the Wilmot instruments were purchased by the University of Guatemala, 1 by the Stanford Research Institute, and 20 by the U. S. Coast and Geodetic Survey (in addition to the 45 Sprengnether Seismoscopes). Of the N. S. F. Wilmot Seismoscopes, one was sent to the University of Cuyo, San Juan, Argentina, and another to the University of Roorkee, Roorkee, U. P., India, to serve as samples for the development of local networks. It is also understood that a group of 50 seismoscopes is being constructed in Chile from the plans included in ref. 4.

13. Acknowledgments. The design and construction of the prototype seismoscope was carried out by the U. S. Coast and Geodetic Survey under the direction of Elliot B. Roberts, Chief, Division of Geophysics. Numerous contributions to the program were made by W. K. Cloud, Chief, Seismological Field Survey, U. S. Coast and Geodetic Survey, and by various members of his staff, including Richard P. Maley, John Hershberger, and Charles K. Knudson. C. Martin Duke and David J. Leeds of the University of California at Los Angeles made the studies on seismoscope location, and assisted with the arrangements for the installation of the instruments. Many useful suggestions for the production of the standard model were made by J. J. Wilmot, of the Wilmot Engraving and Instrument Company. Howard C. Merchant, graduate student in Mechanical Engineering at the California Institute of Technology, assisted with laboratory testing of the early models, and J. L. Alford of the Department of Engineering, Harvey Mudd College, Claremont, conducted the original field tests made during the Corona quarry blast. R. B. Vaile of the Department of Physics, Stanford Research Institute, kindly made available the information on the first actual earthquake measurements made with the seismoscope.

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Table I

SIMULTANEOUS SHAKING TESTS-COMPARISON OF PEAK AMPLITUDES

Each test involves a pair of instruments. The entry (***) indicates the instrument having the smaller amplitudes. The number is the percentage by which the reading of the other instrument is greater.

Test No.	Instrument No.					
	139	140	141	142	143	144
1		***	6-7			
2	8.5	***				
3	***		2			
4			7	***		
5		2		***		
6		***			±1.3	
7	7				***	
8		***				2.3
9	2.3					***

Table II

COMPARISON OF STANDARD U. S. C. G. S. SEISMOSCOPE AND

COMPLETE RESPONSE SPECTRUM ANALYSIS FOR EARTHQUAKES

Station and Earthquake	Component	Peak Acceleration g's	Maximum Relative Velocity Response Spectrum at T = 0. 8 sec, n = 10% critical	
			S_v - Seismoscope	S_v - Accelerogram Analysis
Hollister, California 19 January 1960	SIW	0. 04	0. 24	0. 22
	N89W	0. 06	0. 31	0. 36
Hebgen Dam, Montana 27 August 1959	S30W	0. 04	0. 125	0. 134
	N60W	0. 03	0. 088	0. 085

Table III

LOCATIONS OF WILMOT U. S. C. G. S. SEISMOSCOPES IN SOUTHERN CALIFORNIA

Seismoscope Number	Location	Local Geology
100	Pasadena, Washington Jr. High School 1490 N. Raymond Ave. Ground floor of one-story building.	Crystalline Rock (Monk Hill) surrounded by alluvium. Radius of outcrop approx. 300 ft. Gutenberg 1957 site "WJS". *
101	Pasadena, Star News Bldg., 525 E. Colorado St., Basement of four-story R. C. bldg.	Probably about 900 ft. of old alluvium on crystalline rock.
102	Earthquake Engineering Research Lab, Cal. Tech. Not installed.	
103	Menlo Park, Calif. Corner Ravenswood and Middlefield Aves. Concrete slab in small bldg. Purchased by Stanford Research Institute.	
104	EERL, Cal. Tech. Not installed.	
105	University of Roorkee, Roorkee, U. P. India.	
106	U. S. C. G. S. Seismological Field Survey. To be installed.	
107	Arrowhead Springs, California U. S. Forest Service Bldg.	Basement complex of Jurassic (?) granitic intrusives, principally granodiorite, with granite, diorite, gabbro, or other plutonic rocks.
108	Pasadena, John Muir High School 1905 Lincoln Ave.	

* "Gutenberg sites" refers to Gutenberg, B., "Effect of Ground on Earthquake Motion", Bull. Seis. Soc. Amer., vol 47, No. 3, July 1957

Seismoscope Number	Location	Local Geology
109	Brentwood, C. M. Duke Residence 1110 N. Bundy Dr., Los Angeles 49.	About 30 ft. recent alluvium on canyon floor underlain by a few hundred ft. of terrace deposits or Palos Verdes sand.
110	Alhambra, Mrs. Violet Taylor Residence, 1033 S. Almansor St. Garage floor, separated from one-story frame bldg.	About 1000 ft. of old sediments over several thousand feet of tertiary sediments resting probably on crystalline rock. Ground-water level roughly 150 ft. below surface. Gutenberg 1957 site "VT".
111	Pasadena, J. M. Nordquist Residence, 1695 Corson St. Garage floor, separated from one-story frame bldg.	Probably about 1200 ft. of old alluvium over crystalline rock. Water table about 250 ft. below surface.
112	Office of D. J. Leeds, U. C. L. A. Not installed.	
113	West Los Angeles Public Library, near Santa Monica Blvd. and Sepulveda.	
114	Mount Wilson, Calif. Instrument bldg. of C. I. T. Seis. Lab. S. of 60 in dome of Mt. Wilson Observatory	On crystalline granitic rock. Gutenberg 1928-1951 site "MtW."
115	San Marino, Calif. City Hall, 2200 Huntington Drive. Basement of two-story R. C. bldg.	Probably about 1200 to 1500 ft. of old alluvium over several thousand feet of Tertiary sediments resting on crystalline rock. Raymond fault is about 3000 ft. NW. N of fault crystalline rock is much closer to surface than S. Ground water level about 300 ft below surface. Gutenberg 1957 site "SMC".

Seismoscope Number	Location	Local Geology
116	Riverside, Calif. Lincoln Elementary School.	Possibly 200 ft. older continental alluvium overlying basement granitic rock. Alluvium is mostly poorly sorted clay, sand and gravel, fanglomerates, and weathered soils. Generally poor foundation.
117	Altadena, Calif. Frank Press Residence, 1972 Skyview Drive. Basement of two-story frame bldg.	Several hundred feet of old alluvium on crystalline rock. About 800 ft. SW of Sierra Madre fault and outcrop of crystalline rock. Gutenberg 1957 site "FP".
118	Argentina, University of Cuyo, San Juan	
119	El Centro, Calif. El Centro Water Works	Many hundreds of feet of recent Pleistocene non-marine sands and clays in center of Imperial Valley.
120	U.S.C.G.S. Seismological Field Survey. To be installed.	
121	EERL, Cal. Tech. Not installed.	
122	San Pedro, Calif. San Pedro High School, 17th Street.	Moderate thickness of Palos Verdes sand.
123	Westchester, Calif. D. J. Leeds Residence, 7643 Truxton Ave. L. A. 45.	About 6000 ft. alluvium on crystalline rock.
124	South Pasadena, Calif. Garfield Elementary School, 540 S. Pasadena Ave. Basement of two-story concrete bldg.	About 300 ft. of old alluvium on crystalline rock. About 2500 ft. NE of Eagle Rock fault and about 2200 ft. E of outcrop of crystalline rock. Gutenberg 1957 site "GES".

Seismoscope Number	Location	Local Geology
125	U. S. C. G. S. Seismological Field Survey. To be installed.	
126	Eagle Rock, Calif. San Rafael Elementary School, 1090 Nithsdale Road, Pasadena, ground floor of two-story R. C. bldg.	On Tertiary Topanga stratified sediments with scattered patches of alluvium on top. Surface of crystalline rock probably several thousand feet deep. The Eagle Rock fault which separates crystalline rock to the north from Tertiary to the south is 100-200 ft. north. Gutenberg 1957 site "SRS".
127	Ballona Creek, Playa del Rey Elementary School, near Jefferson and Centinella.	Flood plain of Ballona Creek, elevation about 20 ft. Area similar to location of No. 123.
128	Pasadena, Calif., Hale Elementary School, 2550 Paloma St., Pasadena. Basement of one-story frame bldg.	About 1000 ft. of old alluvium over crystalline rock. Gutenberg 1957 site "HES".
129	Southgate, Calif. Southgate High School.	Average thick recent and Pleistocene on deep part of sedimentary basin, 23,000 ft. to basement.
130	U. S. C. G. S. San Francisco Office	
131	Table Mountain, Calif. Smithsonian Solar Observatory. U. S. C. G. S. T. S.	On granitic crystalline rock. Half mile north of San Andreas fault.
132	El Centro, California, Imperial Valley Irrigation District Sub-station. U. S. C. G. S. Accelerograph Station.	Many hundreds of feet of recent Pleistocene non-marine sands and clays in center of Imperial Valley.

Seismoscope Number	Location	Local Geology
133	Altadena, Calif., R. Gilman Residence, 416 Devirian Place. Garage floor, attached to one-story frame building.	About 800 ft. of old alluvium over crystalline rock. About one mile south of Sierra Madre fault and outcrop of crystalline rock. Gutenberg 1957 site "RG".
134	South Los Angeles, Calif. Narbonne High School. Between Lomita and Harbor City.	Palos Verdes Hills.
135	Los Angeles, Calif. Subway Terminal Bldg., Broadway between 4th and 5th Sts. 60 ft. underground on streetcar landing under twelve-story R. C. bldg. U. S. C. G. S. Accelerograph Station.	Firmest Los Angeles site, probably Pliocene. Alluvium is relatively thin or wanting. Strongly folded late Tertiary marine sediments.
136	U. S. C. G. S. Seismological Field Survey. To be installed.	
137	Westwood, Calif., U. C. L. A. Unit B Engineering Bldg. four-story R. C. bldg. U. S. C. G. S. Accelerograph Station.	About 200 ft. of alluvium on thin Tertiary sediments on fan of Santa Monica Mountain.
138	Pasadena, Calif. Cal. Tech. Athenaeum, 1201 E. California St. Basement of 2-1/2 story R. C. bldg.	About 900 ft. of old alluvium over crystalline rock. Ground water 100-200 ft. below surface. Gutenberg 1957 site "CIT".
139	Van Nuys, Calif., Van Nuys High School, Cedros Ave. between Victory Blvd. and Vanowen St.	On Quaternary alluvium of San Fernando Valley.
140	U. S. C. G. S. Seismological Field Survey. To be installed.	
141	Glendale, Calif. Herbert Hoover High School.	Several hundred feet of Quaternary alluvium.

Seismoscope Number	Location	Local Geology
142	Riverside, Calif., C. I. T. Seismological Laboratory Station.	In granitic Jurassic (?) basement complex. East of Riverside.
143	Colton, Calif., Edison Co. Distribution Station, South of Colton. One-story R. C. bldg. U. S. C. G. S. Accelerograph Station.	On Quaternary Santa Ana river gravel and sands.
144	San Bernardino, Calif., U. S. Post Office and Court House. Basement of two-story R. C. bldg. U. S. C. G. S. Weed Recorder Station.	Several hundred feet of continental Quaternary sands, clay, and gravel. Thickness less than at Colton.
145	Los Angeles, Calif., Occidental Life (Chamber of Commerce) Bldg., 12th and Broadway. Basement of fourteen-story R. C. bldg. U. S. C. G. S. Accelerograph Station.	Several hundred feet of Quaternary alluvium on Tertiary.
146	Hollywood, Calif. Hollywood Storage Co., Cahuenga at Santa Monica Blvd. Small bldg. adjoining P. E. lot. U. S. C. G. S. Accelerograph Station.	On several hundred feet of rather coarse alluvium, resting on some hundreds or thousands of feet of Tertiary sedimentary formations, which in turn rest on slates or possibly some other crystalline bedrock. Immediately under the station - soft alluvium. Water table probably some tens of feet below surface.
147	Long Beach, Calif., Public Utilities Bldg., U. S. C. G. S. Accelerograph Station.	Soft alluvium, tens or hundreds of feet to relatively soft young marine formations underlying whole L. A. plain. Below these 5-10 thousand feet of tilted Tertiary formations, below which are schists and other old crystalline rocks.
148	Vernon, Calif., Central Manufacturing District Terminal Bldg., near 48th & Soto Sts. Basement of eight-story R. C. bldg. U. S. C. G. S. Accelerograph Station.	Deep alluvium near the Los Angeles river. 25-30 thousand feet Tertiary rock. Seismically unstable region.

Seismoscope Number	Location	Local Geology
149	Terminal Island, Calif., Southern California Edison Co. Plant. U.S.C.G.S. Accelerograph Station.	200 ft. recent non-marine, 800 ft., coarse San Pedro sand (Lower Pleistocene). 1000 ft. Upper Pliocene sand, 1000 ft. Lower Pliocene Depette glauconitic siltstone, and 3000 ft. Miocene shales, for a total of about 6100 ft. to the Jurassic (?) Catalina schist basement.
150	Los Angeles, Calif., Edison Bldg., 5th & Hope. Sub-basement of six-story R.C. Bldg., U.S.C.G.S. Accelerograph Station.	365 feet of blue clay resting on late Tertiary unconsolidated marine sediments several thousand feet thick, highly folded and tilted. Below this early Tertiary and Cretaceous resting on older bedrock.
151	Pasadena, Calif., N. Motta Residence, 1545 Ontario Ave. On concrete slab of hobby shop about 20 ft. from one-story frame house.	Probably less than 100 ft. of old alluvium over crystalline bedrock which outcrops about 800 ft. north Gutenberg 1957 site "NM".
152	Pasadena, Calif. C.I.T. Seismological Laboratory, 220 N. San Rafael Ave. Basement of R.C. Instrument Bldg.	On crystalline rock of granitic character, weathered near surface. About 1000 ft. east rock dips under alluvium; about 3000 ft. to SW is Eagle Rock fault which separates the crystalline rock from thick Tertiary sediments of Middle Miocene. Gutenberg 1957 site "SL".
153	Hollister, Calif. Almaden Winery (mounted beside Sprengnether Seismoscope No. 1611 for comparison).	
154	Baldwin Hills, Calif. Windsor Hills Elementary School.	Palos Verdes Terrace, upthrow (north) side of Baldwin Hills Fault.

Seismoscope Number	Location	Local Geology
155	Highland Park, Calif., Mrs. E. Frackelton Residence, 3950 Scandia Way, Los Angeles. Garage built into hill, not connected with stucco building.	On deep Tertiary sediments, in Raymond fault zone, about 300 ft. south of main fault which here separates Topanga formation (Middle Miocene) to the north from the Yorba member of the Puente formation (Upper Miocene) to the South; some alluvium in a narrow valley north of the building. Gutenberg 1957 site "RN".
156	Pacific Palisades, Calif., G. J. Tauxe Residence, 15218 Friends St.	On top of terrace. Several hundred feet of Pleistocene Terrace deposits underlain by thin Tertiary.
157	Los Angeles, Calif., Exposition Park, Museum of Science & Industry of the State of California.	Alluvium.
158	El Centro, Calif. El Centro High School, east of city.	Many hundreds of feet of recent Pleistocene non-marine sands and clays in center of Imperial Valley.
159	U. S. C. G. S. Seismological Field Survey, To be installed.	
160	EERL, Cal. Tech. Not installed.	
161	U. S. C. G. S. Seismological Field Survey. To be installed.	
162	Elysian Park, Calif., Elysian Heights Elementary School, Echo Park Ave.	On Soquel or Yorba member of Puente Formation (Upper Miocene).

Seismoscope Number	Location	Local Geology
163	Compton, Calif., Compton City Schools Administration Bldg.	
164	El Centro, Calif., Imperial Valley Irrigation District Steam Plant, 2 mi. NW of city.	Many hundreds of feet of recent Pleistocene non-marine sands and clays in center of Imperial Valley.

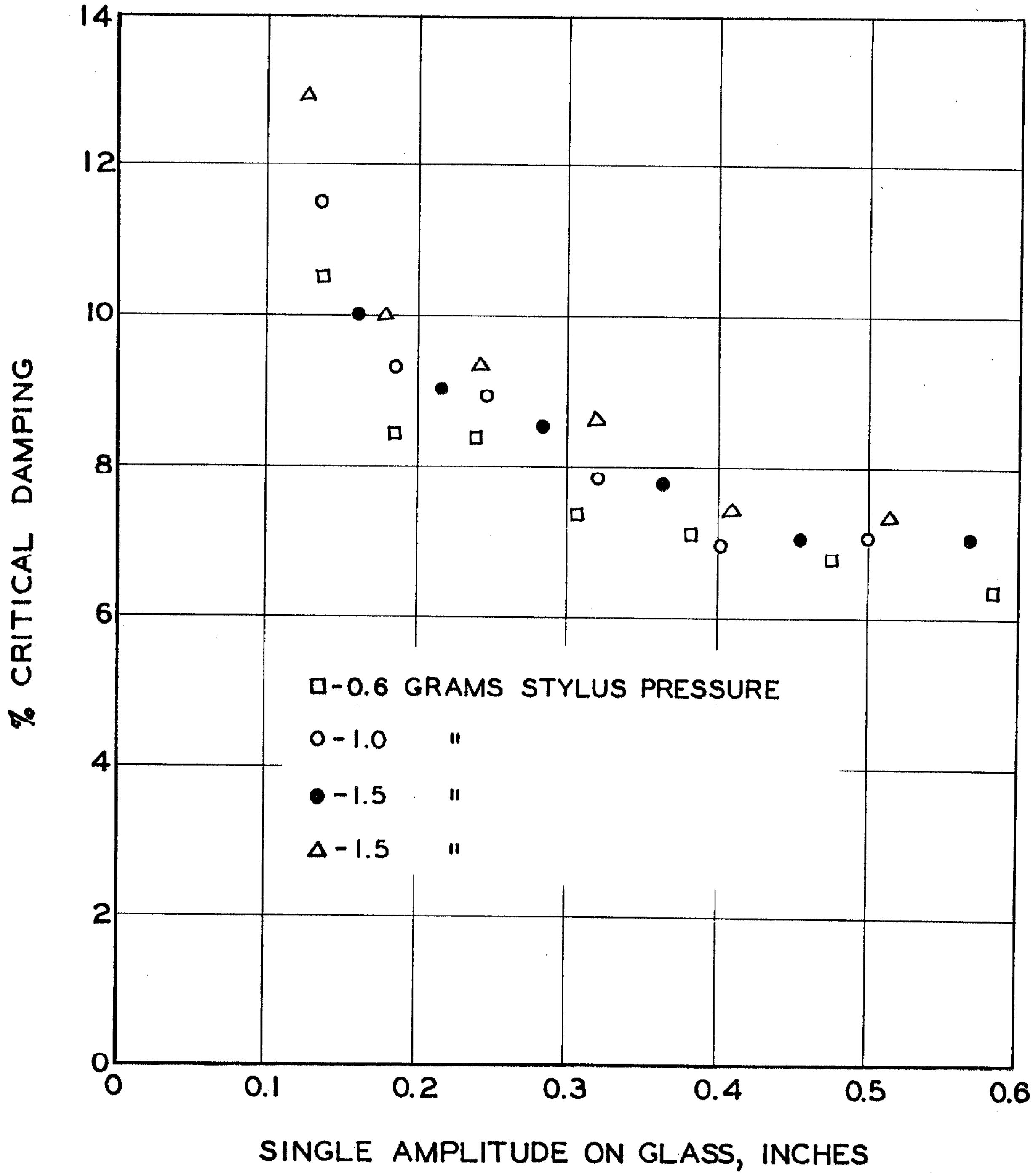


FIG. I EFFECT OF STYLUS PRESSURE ON MEASURED DAMPING

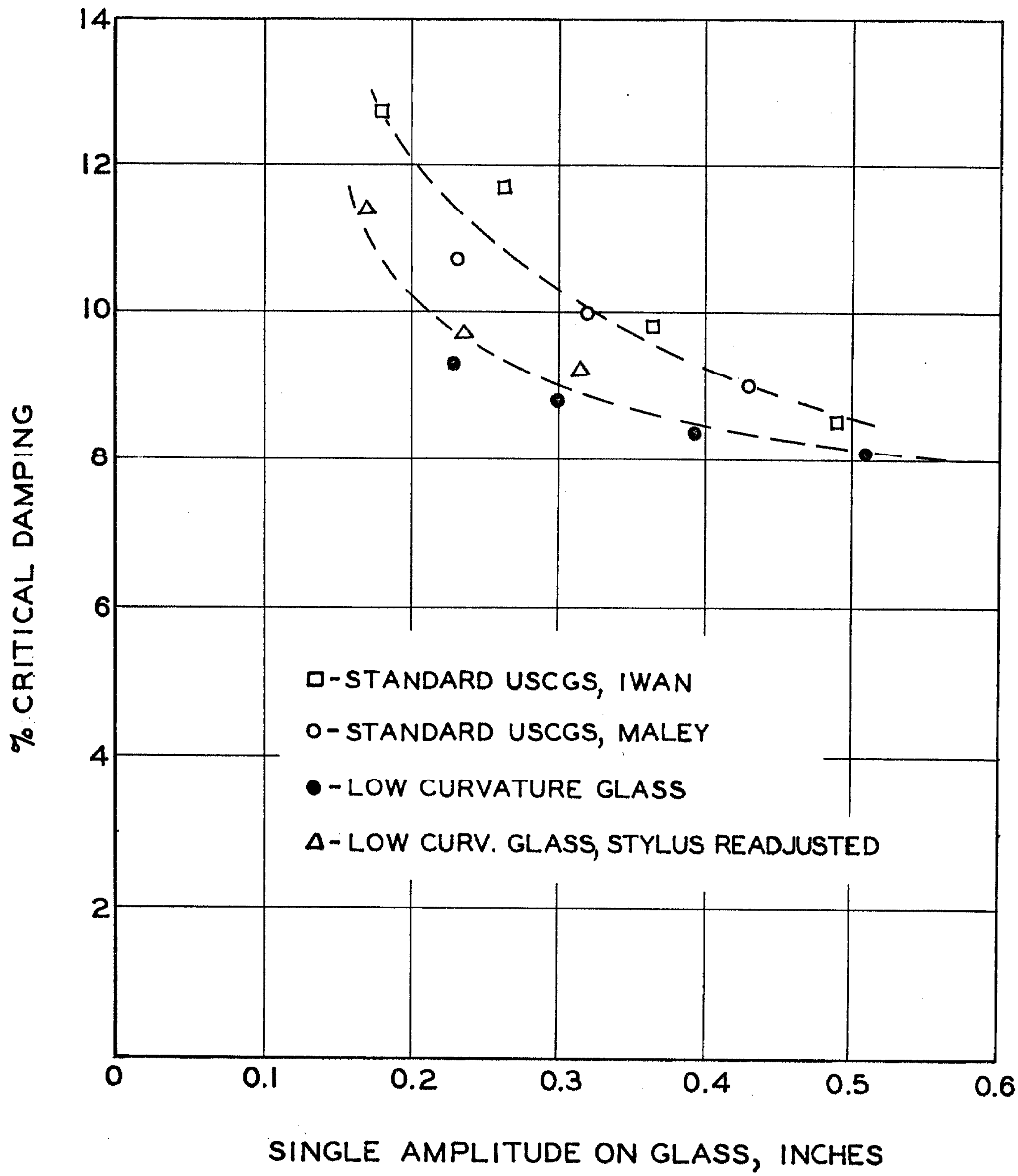


FIG. 2 EFFECT OF GLASS RECORD PLATE CURVATURE ON MEASURED DAMPING.

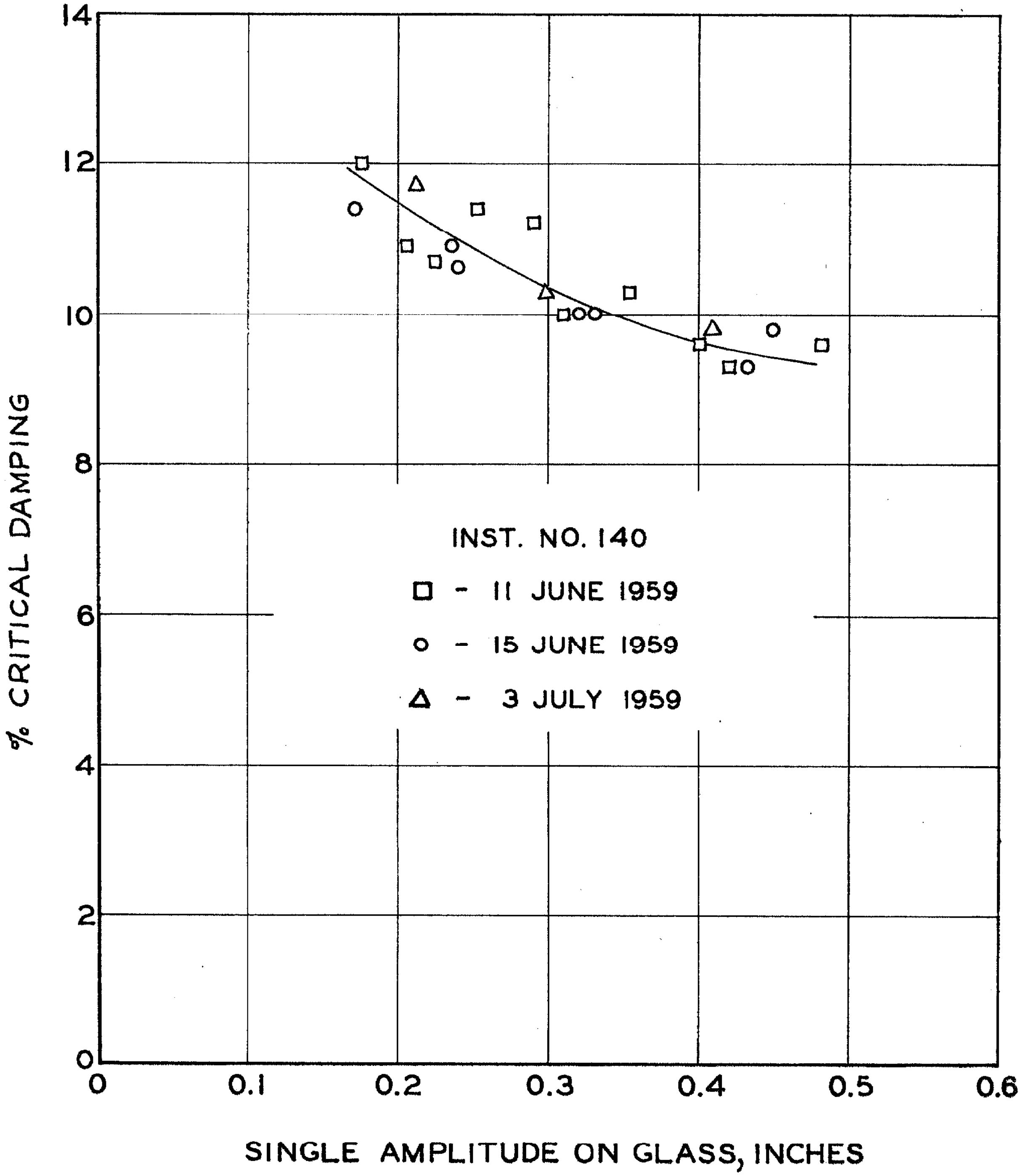


FIG. 3 EFFECT OF REPEATED TEST ON MEASURED DAMPING.

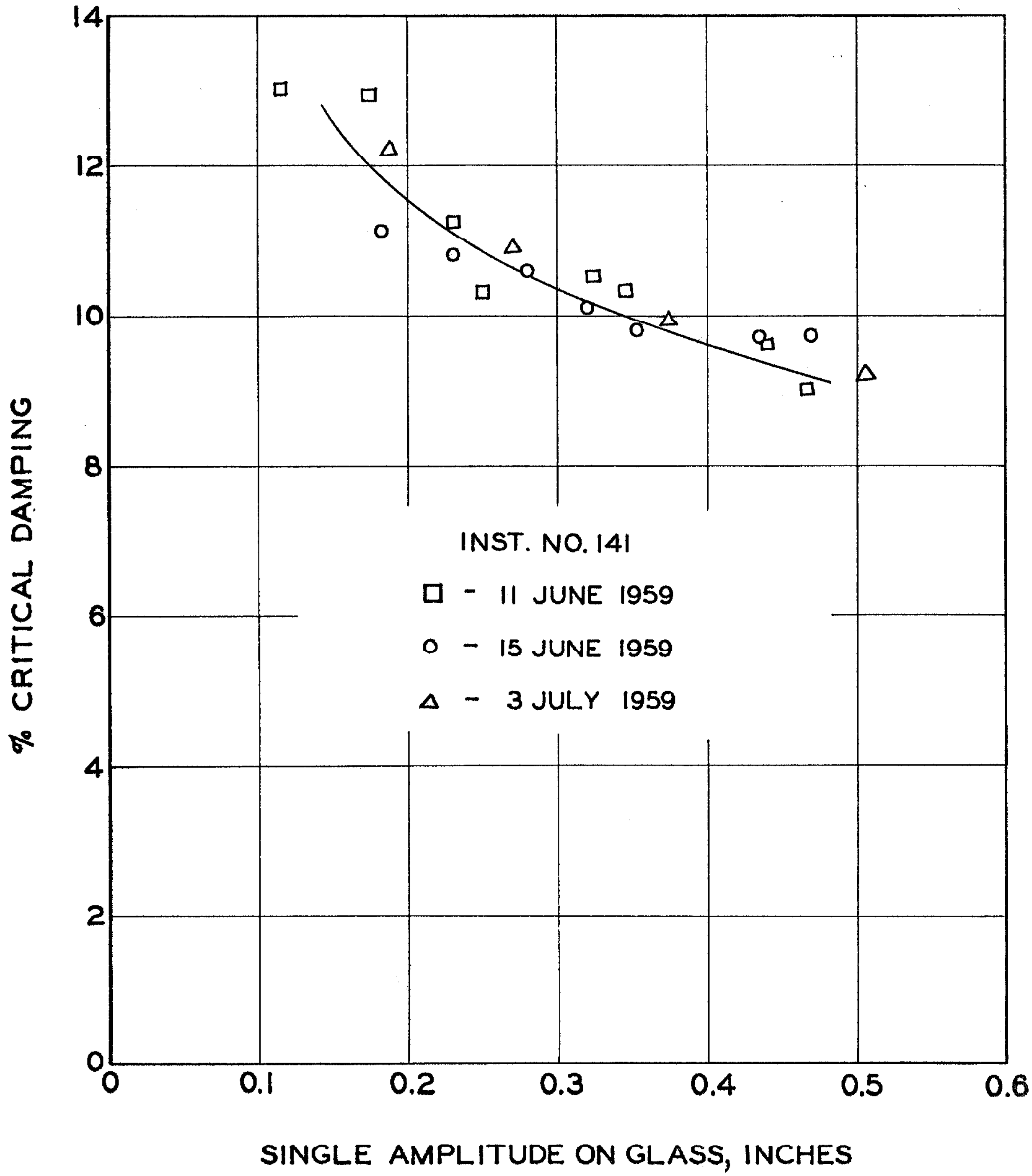


FIG. 4 EFFECT OF REPEATED TEST ON MEASURED DAMPING.

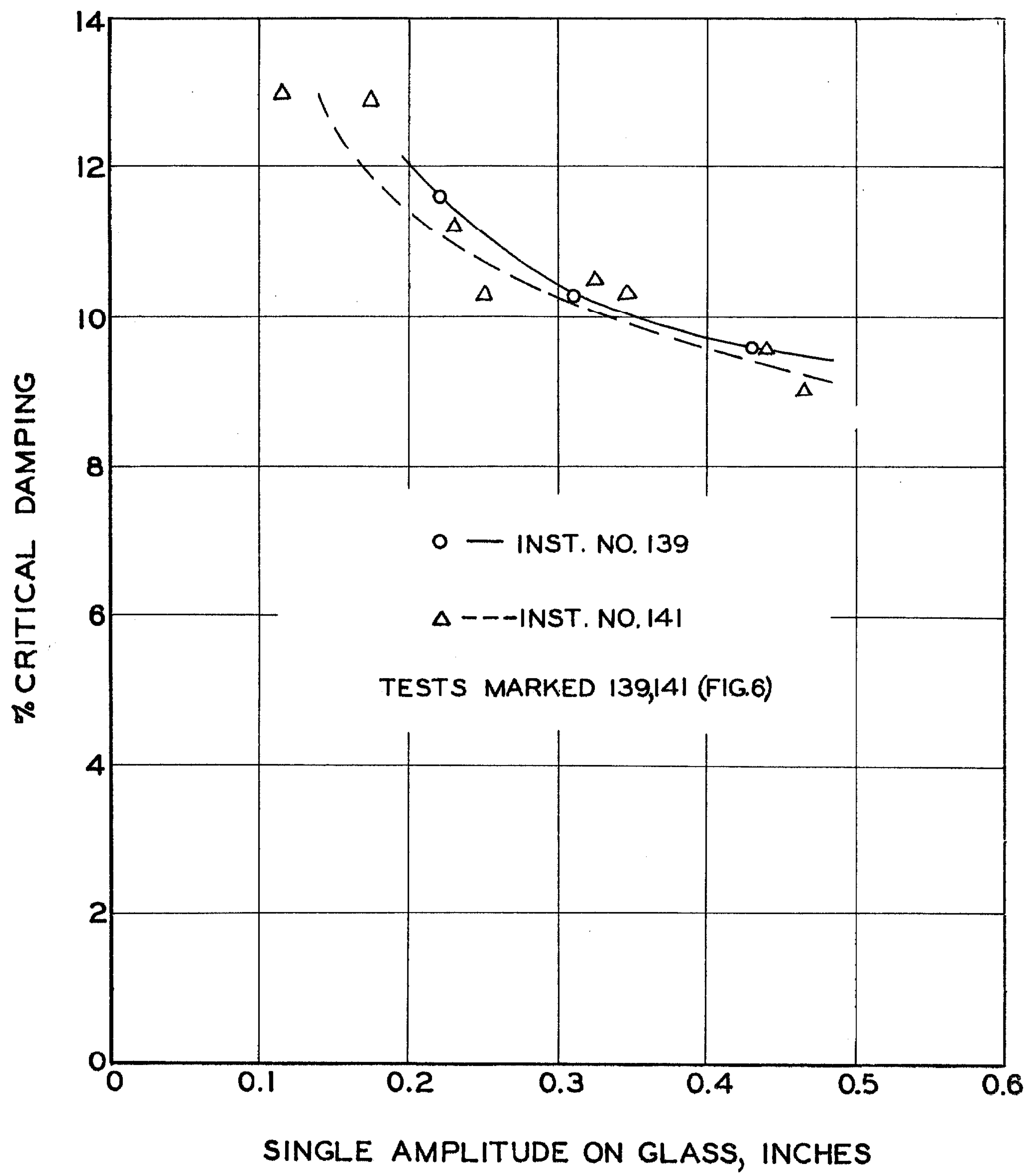
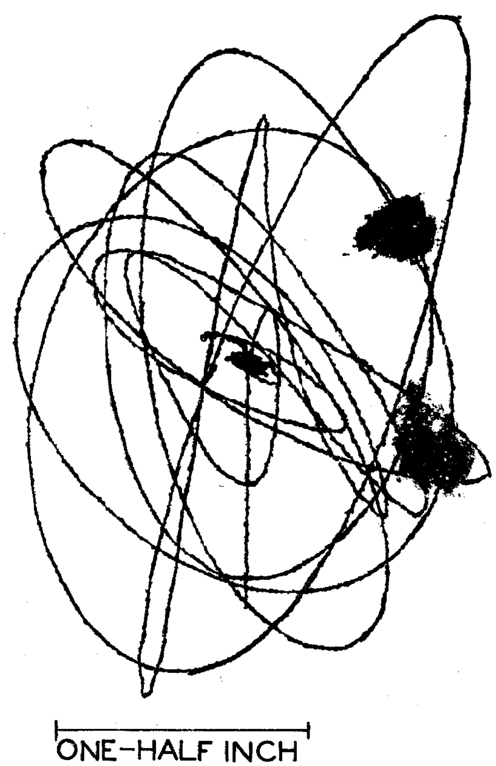
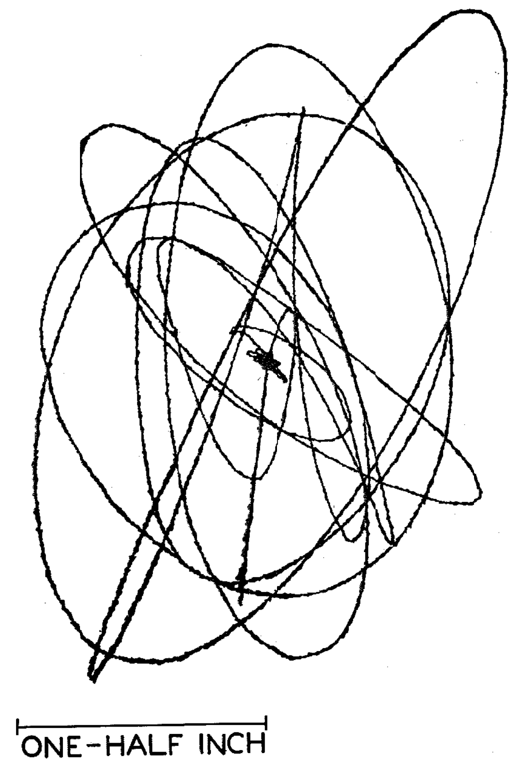


FIG. 5 DAMPING ADJUSTMENT FOR SIMULTANEOUS SHAKE TESTS.



NO. 139



NO. 141

FIG. 6 SIMULTANEOUS SHAKING TEST. SIMILAR DAMPING ADJUSTMENT.

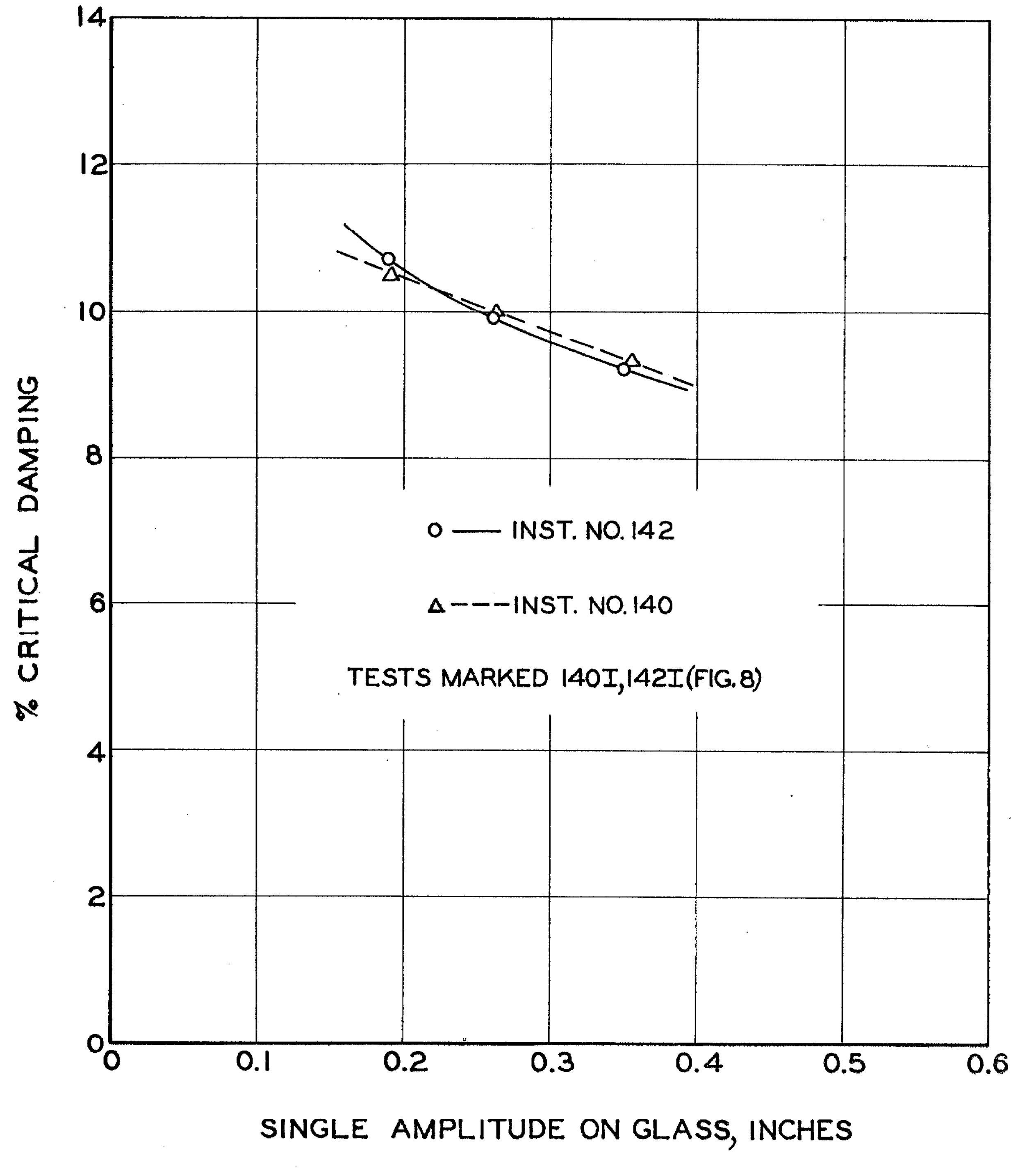
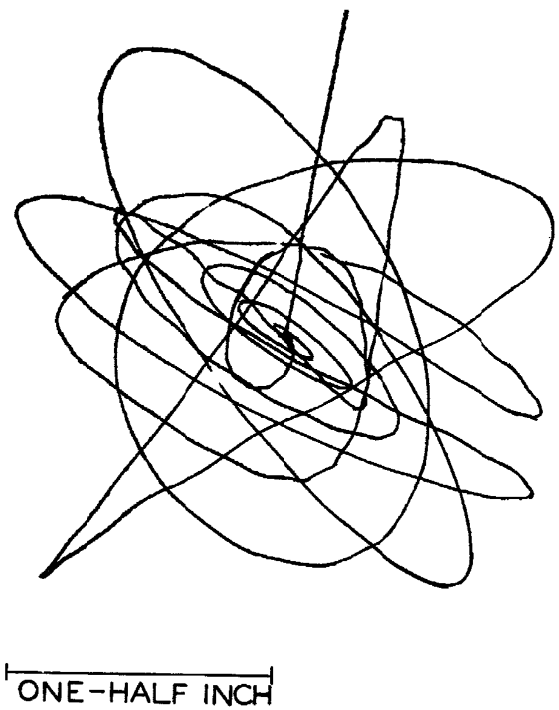
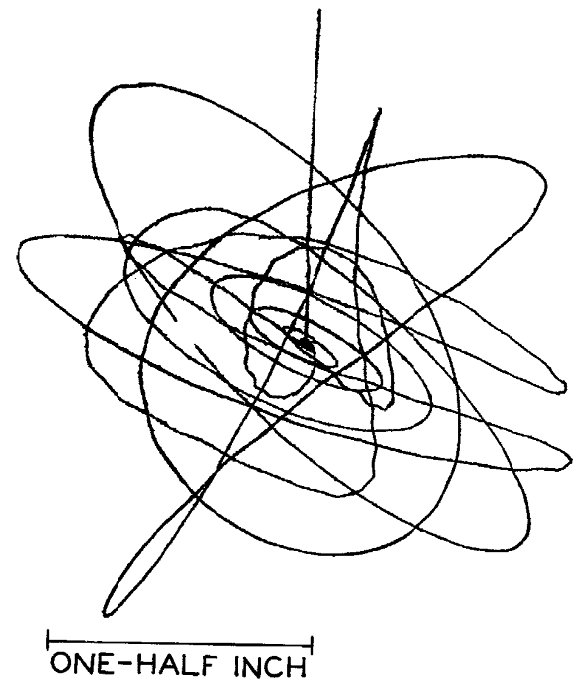


FIG. 7 DAMPING ADJUSTMENT FOR SIMULTANEOUS SHAKE TESTS.



NO. 140-I



NO. 142-I

FIG. 8 SIMULTANEOUS SHAKING TEST. SIMILAR DAMPING ADJUSTMENT.

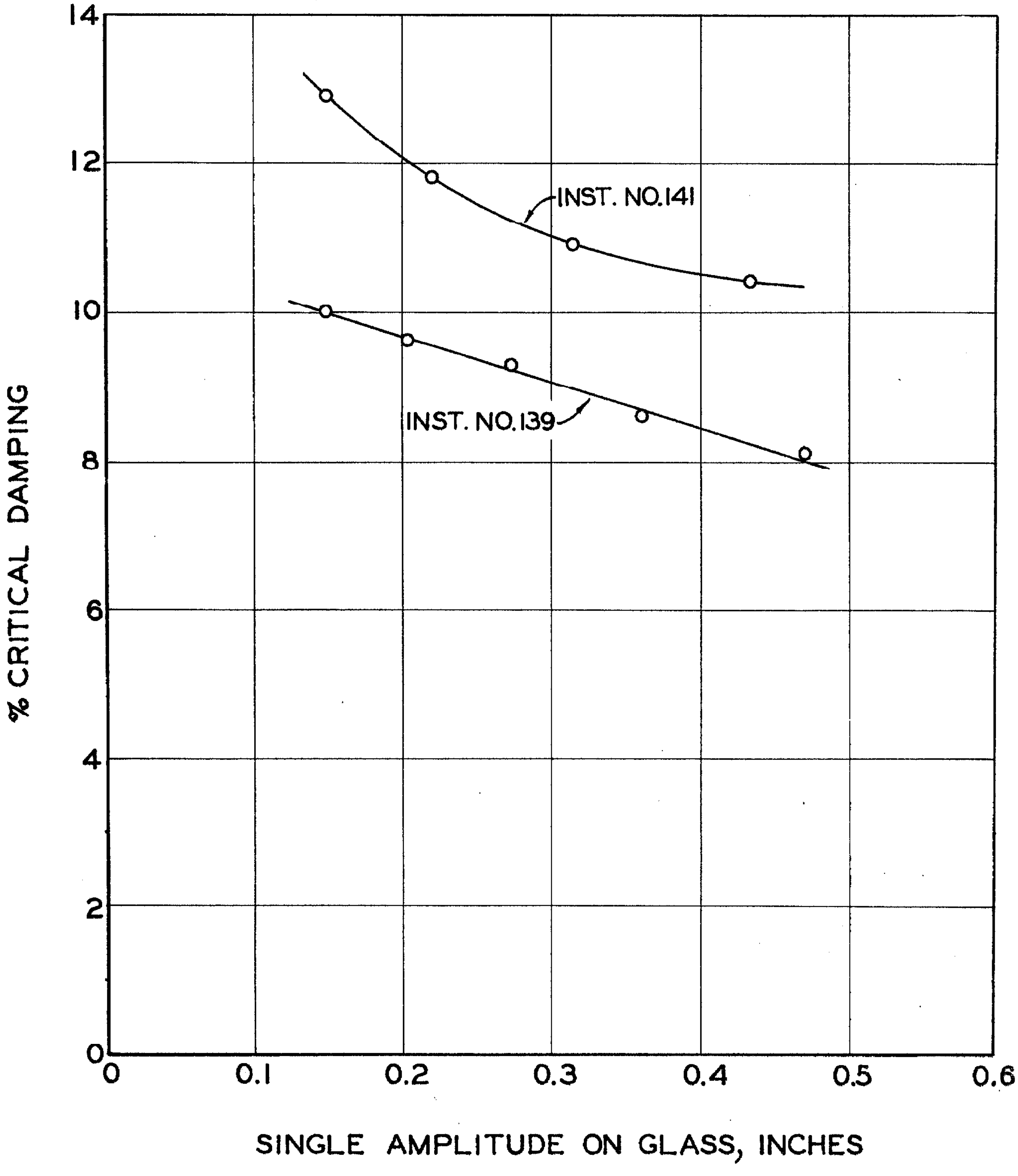
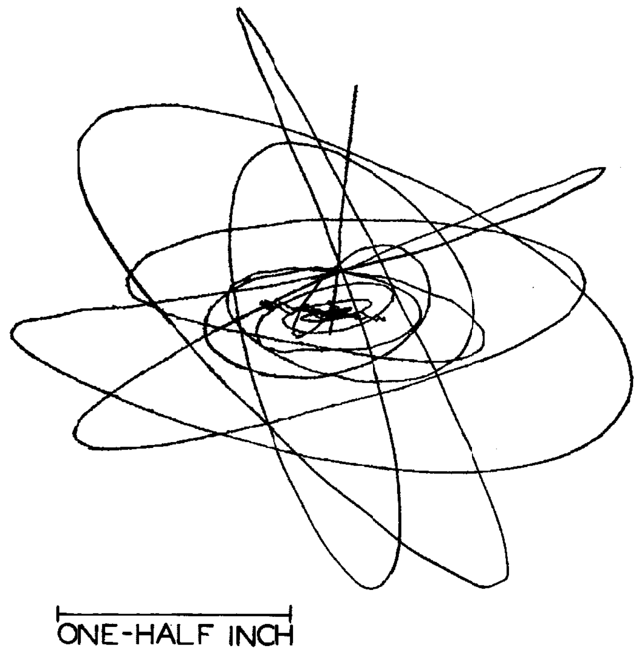


FIG. 9 DAMPING ADJUSTMENT FOR TESTS MARKED 139-II, 141-II (FIG.10) AND 139-III, 141-III (FIG. 11) DAMPING INTENTIONALLY DIFFERENT.



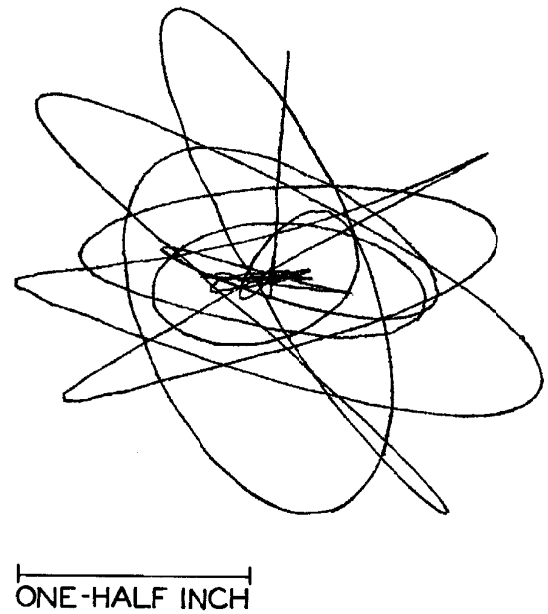
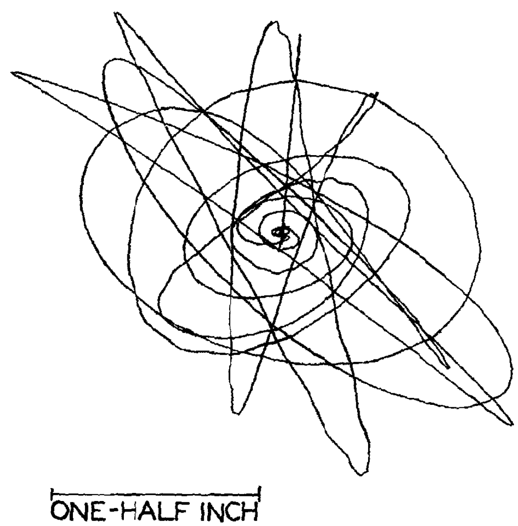
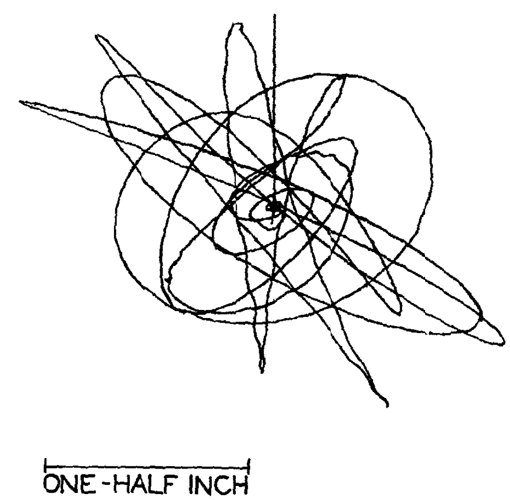


FIG. 10 SIMULTANEOUS SHAKING TEST. DAMPING INTENTIONALLY DIFFERENT (FIG. 9)



NO. 139-III



NO. 141-III

FIG. 11 SIMULTANEOUS SHAKING TESTS. DAMPING INTENTIONALLY DIFFERENT (FIG. 9)

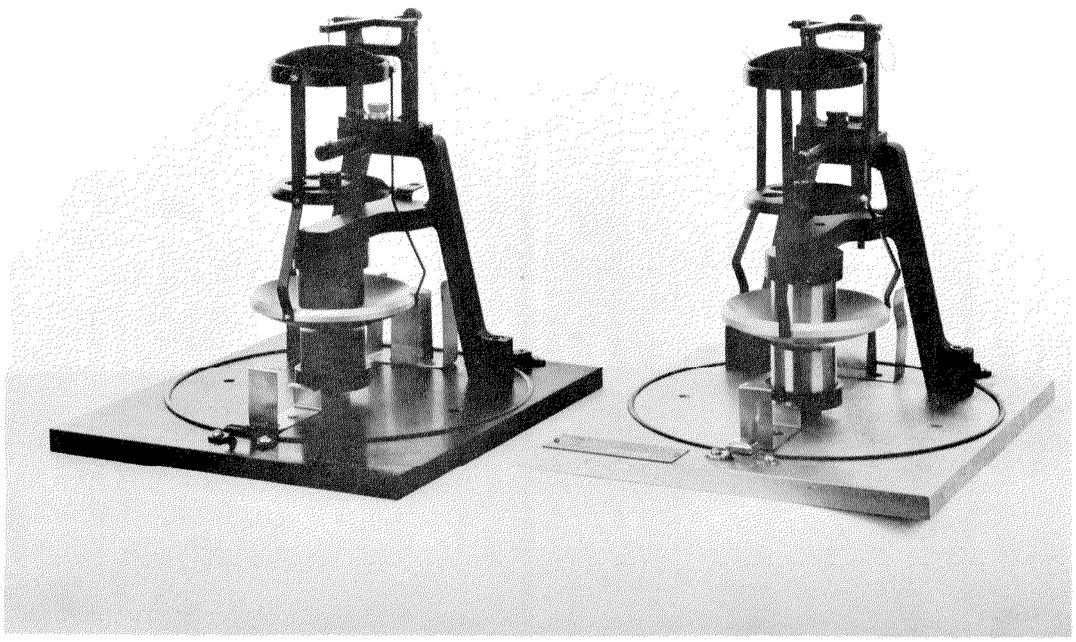


FIG. 12 GENERAL APPEARANCE OF THE WILMOT (LEFT) AND SPRENGNETHER (RIGHT) SEISMOSCOPES WITH PROTECTIVE COVERS REMOVED.

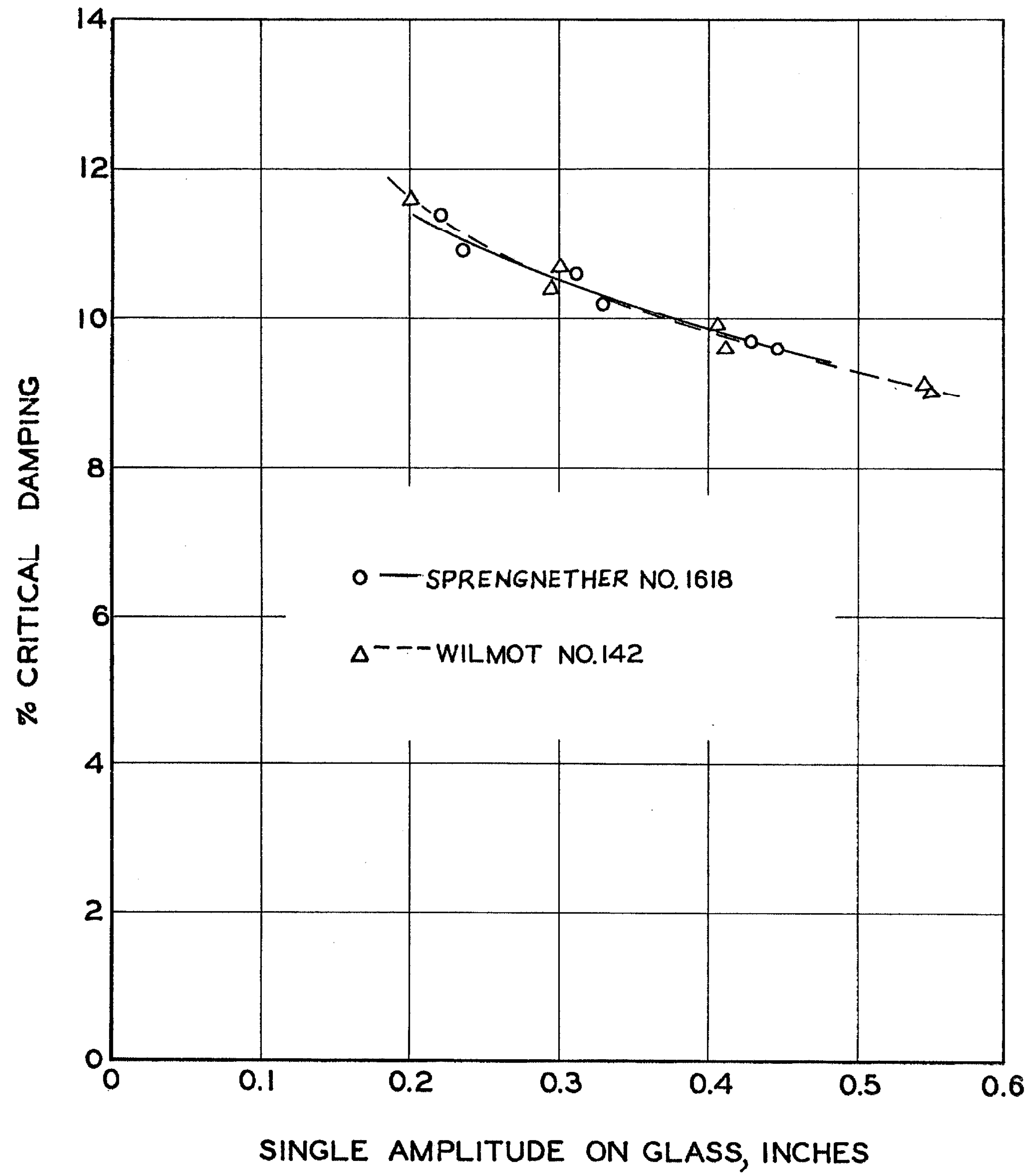
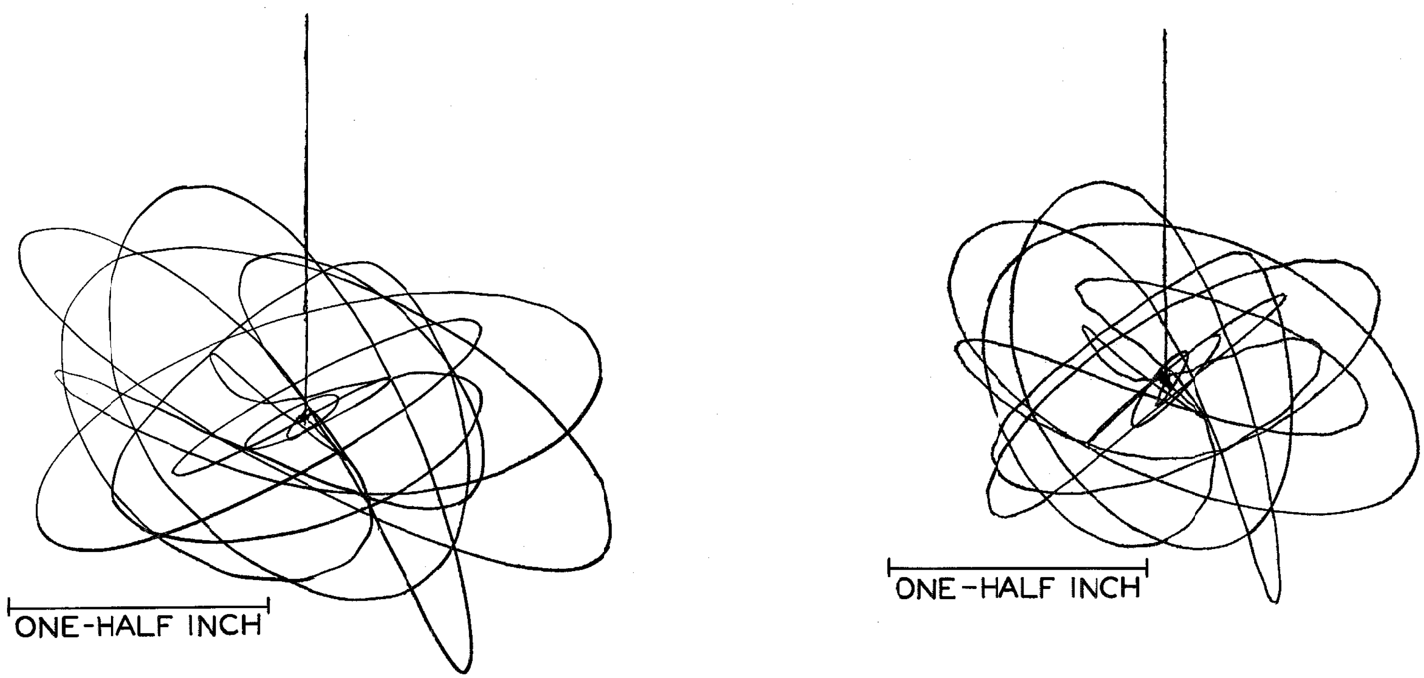


FIG. 13 DAMPING ADJUSTMENT FOR SIMULTANEOUS SHAKING TESTS MARKED 1618-S-I, II, III AND 142-W-I, II, III.

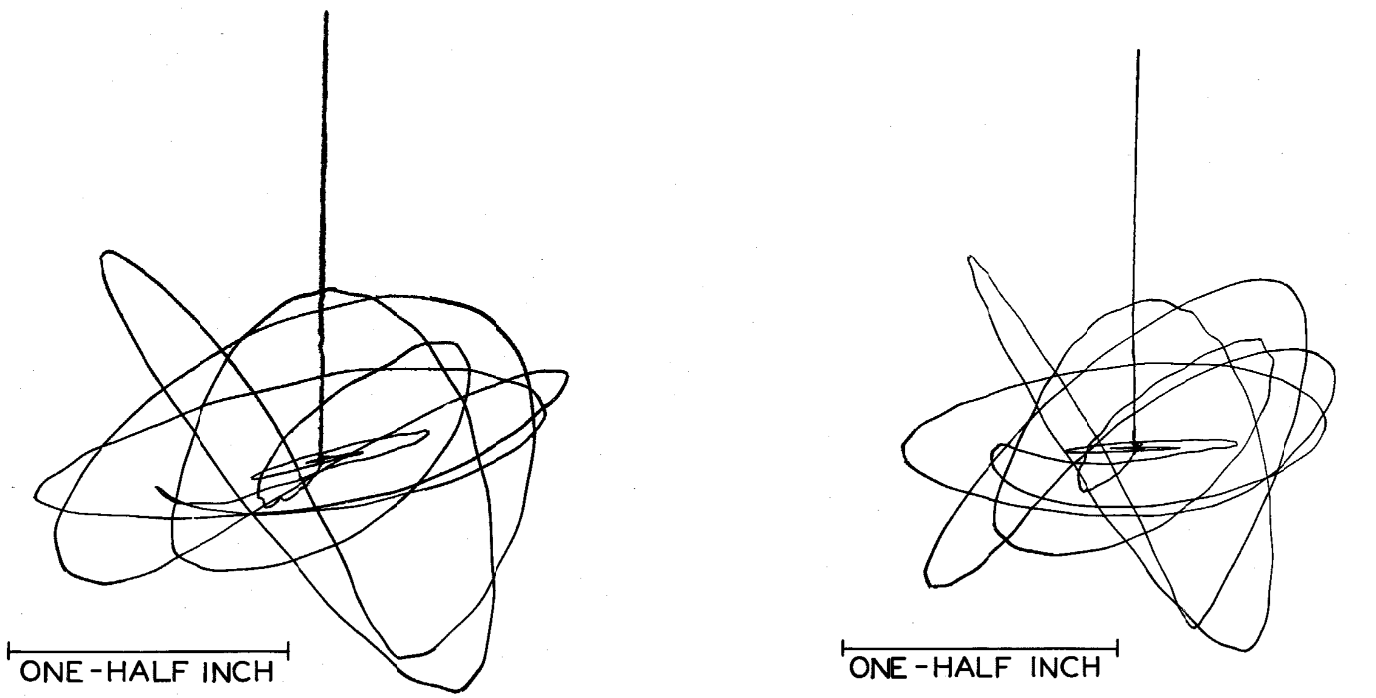
NO. 1618-S-I SPRENGNETHER   NO. 142-W-I WILMOT

FIG. 14 SIMULTANEOUS SHAKING TESTS.



NO. 1618-S-II SPRENGNETHER   NO. 142-W-II WILMOT

FIG. 15 SIMULTANEOUS SHAKING TESTS



NO. 1618-S-III SPRENGNETHER

NO. 142-W-III WILMOT

FIG. 16 SIMULTANEOUS SHAKING TESTS

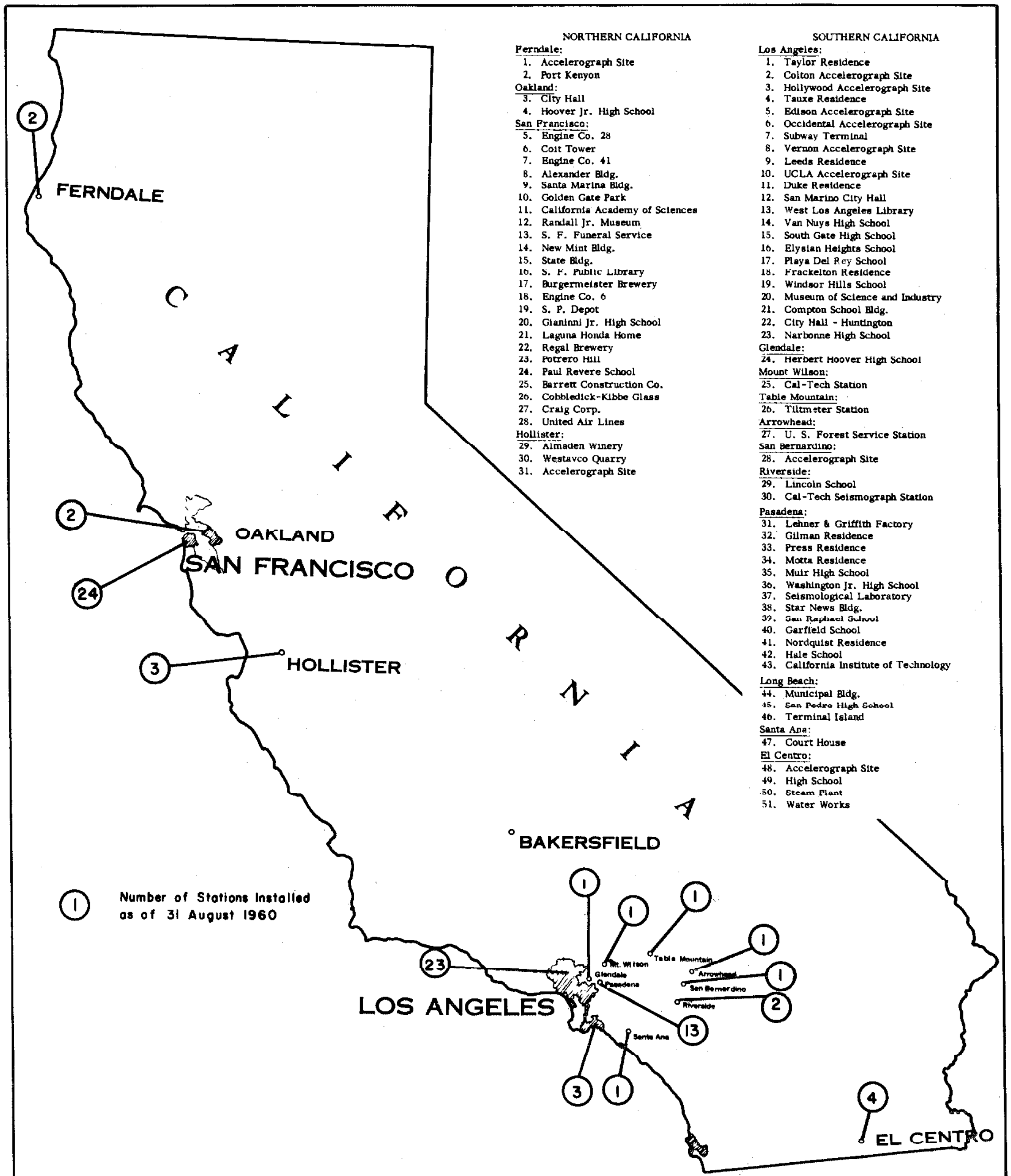


FIG. 17 SEISMOSCOPE STATION LOCATIONS

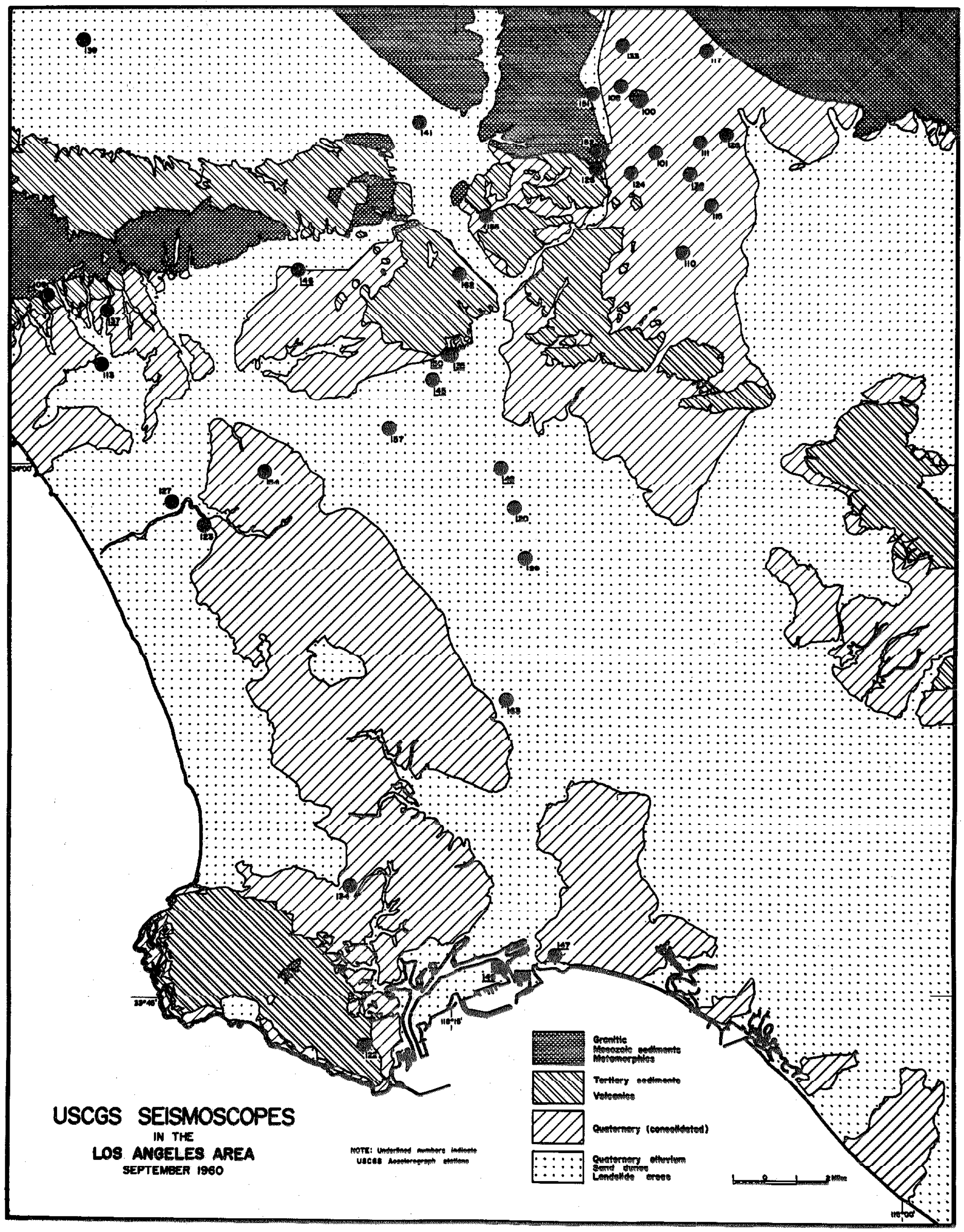

USCGS SEISMOSCOPES
IN THE
LOS ANGELES AREA
SEPTEMBER 1960
NOTE: Underlined numbers indicate
USCGS Accelerograph stations
Granitic
Mesozoic sediments
Metamorphics
Tertiary sediments
Volcanics
Quaternary (consolidated)
Quaternary alluvium
Sand dunes
Landslide areas

FIG. 18